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Short Communication

Measurements of the nasal sacs of individual common dolphin, *Delphinus delphis,* and Dall's porpoise, *Phocoenoides dalli,* by means of silicon reconstruction

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The toothed whales produce a wide range of species specific sounds with great differences between certain families. The acoustic characteristics of the echolocation sounds produced by the Phocoenidae and the Delphinidae are especially different (Kamminga *et al.* 1996). That of the delphinid common dolphin, *Delphinus delphis*, for example, is a broad-band, high-frequency sound of short duration ; the peak frequency range is 20-100 kHz, and the signal duration range is 50-150 μs (Evans 1973). In contrast, the echolocation signal of the phocoenid Dall's porpoise, *Phocoenoides dalli*, is a narrow-band, high-frequency sound of long duration ; the peak frequency range is 120-160 kHz, and the signal duration range is 180-400 μs (Awbrey *et al.* 1979, Hatakeyama and Soeda 1990).

The physical properties of the sounds produced by toothed whales are directly affected by the morphological characteristics of the air space in the head and by the sound-production mechanism (Aroyan *et al.* 1992). In order to understand how sounds are produced, and why there are such different acoustic characteristics between families, detailed information about the shape and volume of the air spaces is needed. In this paper, we describe a new experimental technique making it possible to obtain this information.

We used a silicon injection technique in order to determine the shape and dimensions of the air spaces in the nasal sacs of individual common dolphin and Dall's porpoise. Two specimens, one common dolphin (male, B. L. = 157 cm, M30116, National Science Museum, Tokyo) and one Dall's porpoise (sex and B. L. unknown, collected at Otsuchi, Japan) were examined. The heads of both specimens were frozen before examination. Prior to injecting silicon, the larynx and the surrounding muscle complex of each animal was removed and the head was turned upside down. We then poured 200 ml of KE12 silicon (Shin-etsukagaku Kogyo Co., Tokyo, Japan) into the bony nares and kept the heads in position for eight hours. KE12 silicon is relatively tough, polymerises at room temperature when mixed with one or more catalysts and solidifies after approximately eight hours at 25°C.

The silicon is prevented from entering the air space between the external nares and the blowhole by the nasal plug muscle. This muscle originates chiefly on the premaxilla anterior to the premaxillary sac with a few fibers arising in the connective tissue band along the margin of the premaxilla lateral to the sac (Lawrence and Schevill 1956).

Following solidification of the silicon, the heads were returned to their natural position with the blowhole pointing upwards in order to reconstruct the air space between the external nares and the blowhole. This was done by injecting 100 ml of silicon into the blowhole using a 200-ml plastic syringe with a surgical tube inserted 2-3 cm into the nasal passage. Air in the deep nasal sac was ejected by the pressure of the fluid silicon passing through the blowhole. This second injection of silicon was also allowed to harden for eight hours at room temperature. The hardened silicon was finally removed by dissecting the heads.

Examination of the silicon cast of the nasal sacs of the common dolphin specimen (see Fig. 1) revealed that the left vestibular sac measured 3.5 cm along the anterior-posterior axis, and 2.9 cm transversely, whereas the right vestibular sac measured 4.0 cm by 3.5 cm. The anterior nasofrontal sac was 4.0 cm long, and the posterior nasofrontal sac 3.8 cm long. Eight small diverticula were found between the anterior and posterior nasofrontal sacs. The right accessory sac was 2.2 cm long. The premaxillary sacs were measured 6.3 cm by 2.5 cm (left), and 8.0 cm by 4.7 cm (right). Silicon was not injected into the left nasofrontal sac. The total volume of the nasal air space of this individual common dolphin was found to be 33.3 cm^3.

Examination of the silicon cast of the nasal sacs of the Dall's porpoise specimen (see Fig. 2) revealed that the left vestibular sac measured 4.5 cm along the anterior-posterior axis and 4.2 cm transversely, and that the right vestibular sac measured 7.5 cm by 5.2 cm. The left premaxillary sac measured 4.5 cm along the anterior-posterior axis and 2.4 cm transversely, whereas the right premaxillary sac measured 3.5 cm by 2.3 cm. Silicon was not injected into the nasofrontal sac or the posterior nasal sac. The volume of the nasal air space of this individual Dall's porpoise was found to be 61.5 cm^3. The silicon injection technique proved an effective way of examining the nasal air spaces in two different species of odontocetes, and revealed that the Dall's porpoise has almost twice the volume of nasal air space, and larger vestibular sacs than the common dolphin.

The results from two-dimensional computer modelling suggest that the source of echolocation signals may be the dorsal burse below the vestibular sacs (Aroyan *et al.* 1992). Furthermore, in order to understand why different toothed whale families produce sounds with different physical characteristics, detailed measurements of the air spaces in their heads are needed. Reconstruction of the air spaces in the heads of odontocetes using silicon facilitates the detailed measurement of both the shape and volume of spaces such as the small

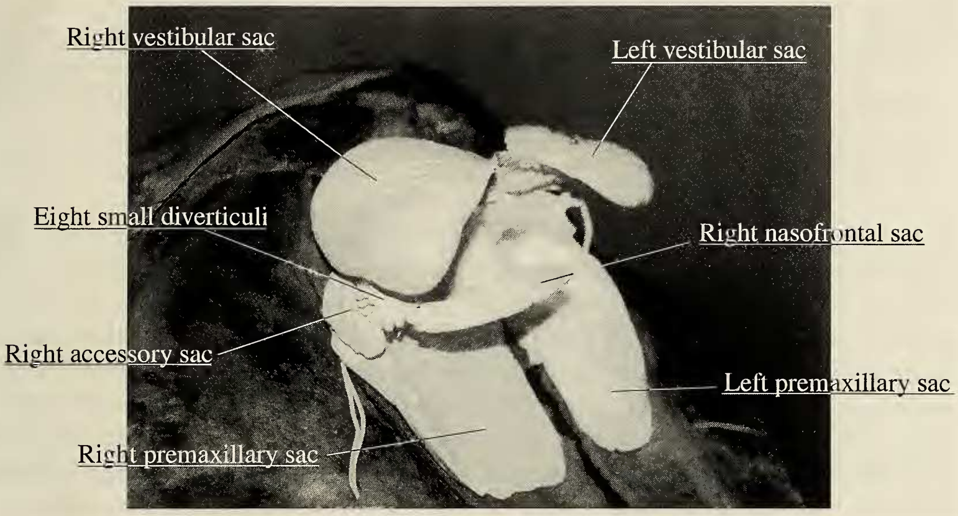

Fig. 1. Silicon reconstruction on the nasal sacs on a common dolphin skull. Skull width (Zygomatic width) = 16.9 cm. Skull length (Condylobasal length) = 41.3 cm.

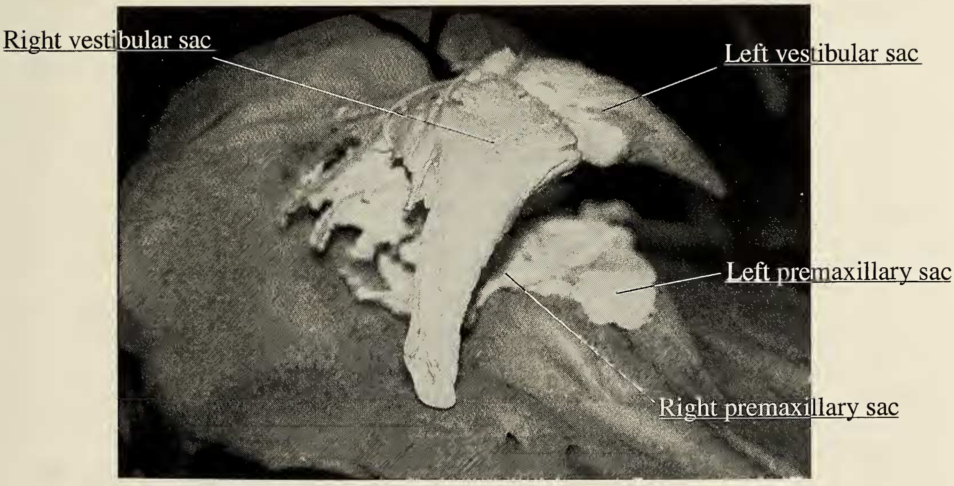

Fig. 2. Silicon reconstruction on the nasal sacs on a Dall's porpoise skull. Skull width (Zygomatic width) = 18.6 cm. Skull length (Condylobasal length) = 33.5 cm.

nasofrontal diverticula, and this technique may prove valuable in studies of sound production. In recent years, new medical imaging techniques such as x-ray computed tomography (CT) and magnetic resonance imaging (MRI) have been used to describe the internal details of the foreheads of toothed whales (Cranford 1988, Amundin and Cranford 1990, Amundin 1991, Cranford *et al.* 1996). Future research into the sound production mechanisms of odontocetes may benefit from incorporating both silicon reconstruction of nasal regions and CT and MRI medical imaging techniques along with three-dimensional computer modelling.

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